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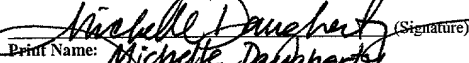
**METHOD FOR ENHANCING A DIGITAL IMAGE WHILE SUPPRESSING**  
**UNDERSHOOTS AND OVERSHOOTS**

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# **METHOD FOR ENHANCING A DIGITAL IMAGE WHILE SUPPRESSING**

## **UNDERSHOOTS AND OVERSHOTS**

### BACKGROUND OF THE INVENTION

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### FIELD OF THE INVENTION

The present invention relates to a method for enhancing a digital image while  
suppressing or preventing undershoots and overshoots that normally occur as a result of  
such enhancement.

There are many ways of acquiring digital images based on current technologies.  
For example, digital images can be obtained with a digital camera, with a scanner, or can  
be downloaded from the Internet. Video signal capturing systems also provide ways of  
getting digital image samples or video samples. Digital images are also internally  
available and processed in some multimedia devices such as DVD players and Digital TV  
systems.

Images tend to degrade for various reasons, and in order to obtain better quality,  
these images need to be enhanced. Many image enhancement processes are known and a  
particular one of these processes can be selected depending upon the degradation  
characteristics of an image. Local contrast enhancement enhances the visual cue of a

given image and is also referred to as detail enhancement. The fundamental concept behind detail enhancement is to emphasize the high frequency components that are embedded in the image so that the visual appearance of the image can be sharpened or can appear more vivid to a human being.

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The most commonly used methods of detail enhancement are based upon unsharp masking. Examples of unsharp masking can be found by referring to the following references, which are incorporated herein by reference: Jain, Anil K. *Fundamentals of Digital Image Processing*, Prentice Hall, 1989. p. 249; and Lim, Jae S. *Two Dimensional Signal Processing and Image Processing*, Prentice Hall, 1990. p. 459. A more complex method of enhancement is disclosed in Kim, Yeong-Taeg (U.S Patent No. 5,930,402) *Method and Device for Local Contrast Enhancement of Video Signal*, which is also incorporated herein by reference.

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Most detail enhancement methods are associated with a problem known as overshoot and undershoot that occurs as the result of the enhancement. Overshoot and undershoot are visually annoying and undesirable. For example, Fig. 1A shows digital image samples that can represent either a vertical edge or a horizontal edge. If a typical detail enhancement method is applied to these samples, the result is as shown in Fig. 1B.

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Note that the slope has been increased, and therefore, the edge has been sharpened around the center of the edge. However, it should be also observed that overshoot and undershoot (the circled areas) are also present in the enhanced image samples shown in Fig. 1B, and as previously mentioned, this overshoot and undershoot are visually annoying and

undesirable if the image is going to be displayed with a display device, such as, for example, a television. Overshoot and undershoot will hereinafter be referred to as "Shoots". A desirable enhancement result might be the one shown in Fig. 1C in which the Shoots have been mitigated. The visual impact of such Shoots is demonstrated in Figs. 2A and 2B. Fig. 2A shows a degraded input image and Fig. 2B shows the result of detail enhancement utilizing unsharp masking that is based on a horizontal high-pass filter. The overall detail or sharpness has been increased significantly in the image shown in Fig. 2B, but the image clearly shows that Shoots resulting from the detail enhancement process are visually undesirable and annoying. In general, the effect becomes more visible and annoying if the image is displayed on a large display device such as a large screen television set.

Hence, it is highly desirable to suppress or prevent the occurrence of the Shoots, causing visually annoying effects, while enhancing the details of an image.

## SUMMARY OF THE INVENTION

It is accordingly an object of the invention to provide a method for enhancing the details of an image while suppressing or preventing shoots that would otherwise occur during a prior art enhancement process.

The enhancing method is based on recognizing that Shoots are likely to occur at edges of an image to be enhanced, and therefore, if the enhancement is sufficiently

reduced or even possibly eliminated at the edges of the image, the Shoots that would otherwise occur will be suppressed or even possibly eliminated. A gain suppressing function is used to attenuate the enhancement at the edges of the image. Preferably, the gain suppressing function inherently identifies the edges of the image to be enhanced.

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With the foregoing and other objects in view there is provided, in accordance with the invention, a method for enhancing an image, that includes steps of: obtaining a first image signal including pixel values; obtaining a high-pass image signal having high-frequency components of the first image signal; obtaining a positive non-zero weighting factor to control a degree of enhancement; selecting edge pixel values representing a boundary of an edge in the first image; for suppressing shoots, defining a gain suppressing function having attenuation coefficients to be multiplied with particular pixel values of the high-pass image signal corresponding in location to the edge pixel values; multiplying the high-pass image signal by the weighting factor and by the gain suppressing function to obtain a result; and adding the result to the first image signal to obtain an enhanced image signal in which the shoots have been suppressed.

In accordance with an added feature of the invention, the selecting step is performed by evaluating two independent boundary-indicating functions and concluding that a given one of the pixel values of the first image represents the boundary of the edge only if both of the two functions indicate that the given one of the pixel values is on the boundary.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A shows digital image samples that represent an edge;

5        Fig. 1B shows the digital image samples of Fig. 1A after undergoing a prior art detail enhancement process;

Fig. 1C shows the digital image samples of Fig. 1A after undergoing a desirable detail enhancement process;

Fig. 2A shows a degraded image;

Fig. 2B shows the image of Fig. 2A after undergoing a prior art detail enhancement process;

Fig. 3 shows the representation of a digital image by an  $M \times N$  array of digital pixels;

Fig. 4 shows a prior art detail enhancing circuit;

Fig. 5 shows a detail enhancement circuit that suppresses or prevents shoots;

Fig. 6 shows an input sample that is located in the middle of a spike signal;

Figs. 7A-7D show image samples of four possible cases that can be used to better understand the combined condition for detecting the boundary of an edge; and

Fig. 8 shows a plot of a first exemplary embodiment of the Shoot suppressing  
5 gain function  $\beta$ .

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will first be described in relation to a method for enhancing  
10 a digital image while preventing or suppressing the occurrence of Shoots in the horizontal direction. However, the invention is also applicable to enhancing the digital image while preventing or suppressing the occurrence of shoots in the vertical direction.

For systematically describing the present invention, some mathematical notations  
15 will be introduced. When acquiring digital image samples, it is typical to model the digital image as a two-dimensional signal having horizontal and vertical indices where the functional value corresponds to the pixel value. That is, suppose that

$\{f\}_{M \times N}$  represents a digital image or a digital picture composed of  $M \times N$  digital pixels in which  $M$  and  $N$  represent the height (the number of the samples in the vertical direction,  
20 or the number of the lines) and the width (the number of the samples in horizontal direction), respectively. Then  $f(m,n)$  represents the  $n$ th pixel value of the  $m$ th line of the input image,  $\{f\}_{M \times N}$ . This relationship is depicted in Fig. 3.

A more thorough description of detail enhancement based on unsharp masking can be found by referring to the references mentioned in discussing the background of the invention. The unsharp masking process is based on adding a signal proportional to the gradient, or a high-pass signal, to the given image. This process is illustrated in Fig. 4, which shows a prior art detail enhancing circuit 10 with a detail signal computer 12 that provides a high-pass filtered image of the input image. In general, the unsharp masking operation can be written as:

$$\{g\}_{M \times N} = \{f\}_{M \times N} + a \cdot \{h\}_{M \times N}$$

where  $\{g\}_{M \times N}$  represents the output image,  $\{h\}_{M \times N}$  represents a high pass filtered image of  $\{f\}_{M \times N}$ , and  $a$  is a predetermined non-zero positive constant (weighting factor) that controls the degree of enhancement.

The unsharp masking process can be equivalently expressed as a pixel by pixel process such that

$$g(m, n) = f(m, n) + a \cdot h(m, n) \quad (1),$$

where  $g(m, n)$  and  $h(m, n)$  represent the pixel values of  $\{g\}_{M \times N}$  and  $\{h\}_{M \times N}$ , respectively, for  $m = 1, 2, \dots, M$  and  $n = 1, 2, \dots, N$ . Note from (1) that the high frequency components of the input image are added to itself so that details of the image composed of the high frequency components are amplified as a consequence. The overall characteristic of the unsharp masking process is solely dependent on the design of the high pass filter and on the value of the constant  $a$ , which is known as the enhancement gain control parameter.



Methods of designing and analyzing high-pass filters are well-known in the art of image or video signal processing, and therefore such methods will not be discussed in depth in this disclosure. The previously cited documents, “Fundamentals of Digital Image Processing”, and “Two Dimensional Signal Processing and Image Processing”, can also  
5 be referred to for information on this topic.

Some basic examples of high-pass filters will be given. As a first example, a high-pass filter can be expressed as:

$$h(m,n) = f(m,n) - (f(m,n-1) + f(m,n+1))/2 \quad (2),$$

10 which represents a horizontal high pass filter meaning that only the horizontal gradient is taken into account. Similarly, a vertical high-pass filter can be expressed as:

$$h(m,n) = f(m,n) - (f(m-1,n) + f(m+1,n))/2. \quad (3).$$

A 2-dimensional high-pass filter can be expressed as:

$$h(m,n) = f(m,n) - (f(m,n-1) + f(m,n+1) + f(n-1,m) + f(n+1,m))/4 \quad (4),$$

15 which is associated with the average change of the signal in the horizontal and the vertical directions around the sample location at  $(m,n)$ .

The fundamental role of  $h(m,n)$  in (1) is to estimate the local contrast or the local detail of the image. One can use a more sophisticated method for estimating the details of  
20 the image, such as, the method disclosed in U.S. Patent No. 5,930,402, for example. In other words, the current invention is not limited to any particular method of obtaining  $h(m,n)$ , because the main object of the present invention is to suppress or prevent the overshoot/undershoot inherently arising in detail enhancement methods. The present detail

enhancement method, which suppresses or prevents Shoots can be used, for better detail enhancement, in combination with any possible method of obtaining high-frequency components of the image.

Fig. 5 shows a detail enhancement circuit 20 for performing the inventive method of detail enhancement that suppresses or prevents Shoots. The enhanced output signal is given as:

$$g(m,n) = f(m,n) + \beta(m,n) \cdot a \cdot h(m,n) \quad (5),$$

where  $\beta(m,n)$  is the Shoot suppressing gain function ( $0 \leq \beta(m,n) \leq 1$ ), which varies from pixel to pixel depending on the characteristic of the signal at  $(m,n)$ , and where  $a \cdot h(m,n)$  is the general enhancement term. Fig. 5 shows a shoot suppressing gain circuit 22 for generating the Shoot suppressing gain function  $\beta(m,n)$  in a manner that will be discussed below. The detail signal computer 12 has already been discussed in regard to Fig. 4.

The role of the Shoot suppressing gain function in (5) is to adjust the degree of enhancement in order to suppress Shoots when necessary. That is, when it is estimated that Shoots are likely to occur, the value of  $\beta(m,n)$  is made smaller so that the impact of the enhancement can be minimal. Note that the output signal shown in Fig. 5 simplifies to

$g(m,n) = f(m,n)$  if  $\beta(m,n) = 0$ , which means no change or no enhancement is made for the input image. On the contrary, when it is estimated that Shoots are not likely to occur, the value of  $\beta(m,n)$  is made larger so that the input image is enhanced. Note that that the output signal of the process in Fig. 5 simplifies to  $g(m,n) = f(m,n) + a \cdot h(m,n)$

if  $\beta(m,n) = 1$ , in which case, the input image is fully enhanced by  $a \cdot h(m,n)$ . Hence, the fundamental process behind (5) and the enhancement circuit shown in Fig. 5 is using the Shoot suppressing gain function to adjust the degree of enhancement in dependence upon whether or not it is estimated that shoots are likely to occur.

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Now, we turn to the problem of computing the Shoot suppressing gain function  $\beta(m,n)$ , at the presence of the incoming input samples in order to realize the detail enhancement operation with Shoot suppression in (5). Hence, the fundamental question is how to estimate the probability that Shoots are likely to occur when performing an enhancement process. Close observation of the occurrence of Shoots leads one to conclude that Shoots typically occur at the boundary of an edge as shown in Fig. 1B and in Fig. 2B.

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Hence, we turn to the problem of developing a method for detecting the boundary of an edge and generating an associated Shoot suppressing gain function  $\beta(m,n)$  that can be used for performing the enhancement process described by (5) and shown in Fig. 5. To arrive at such a Shoot suppressing gain function  $\beta(m,n)$ , the following quantity is computed:

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$$d(m,n) = \min(f_L(m,n), f_R(m,n)) \quad (6),$$

20 where

$$f_L(m,n) = |f(m,n) - f(m,n-1)| \quad (7), \text{ and}$$

$$f_R(m,n) = |f(m,n) - f(m,n+1)| \quad (8).$$

In order to normalize  $d$ , the following quantity is computed:

$$x(m,n) = \begin{cases} \left(\frac{d(m,n)}{D}\right)^J, & \text{if } d(m,n) \leq D \\ 1, & \text{otherwise} \end{cases} \quad (9),$$

where  $D$  and  $J$  are predetermined positive non-zero constants. Note, it is likely that the sample  $f(m,n)$  is located at the boundary of an edge as the value of  $x(m,n)$  approaches

0. Note also, however, the fact that the value of  $x(m,n)$  approaches 0 does not necessarily indicate that the sample  $f(m,n)$  is located at the boundary of an edge. A small value of  $x(m,n)$  can also be obtained around a constant area in which both values of  $f_L(m,n)$  and  $f_R(m,n)$  are small. Hence, it is not sufficient to determine whether or not the current input sample  $f(m,n)$  is located at the boundary of an edge based only on  $x(m,n)$ .

To compensate for the insufficient condition for determining whether the current input sample  $f(m,n)$  is located at the boundary of an edge, we investigate the amplitude of a horizontal gradient signal as follows. Let us define the normalized amplitude of a horizontal Laplacian signal as:

$$y(m,n) = \begin{cases} \left(\frac{|\Delta(m,n)|}{H}\right)^K, & \text{if } |\Delta(m,n)| \leq H \\ 1, & \text{otherwise} \end{cases} \quad (10),$$

where  $H$  is a predetermined positive non-zero constant value used for normalization,  $K$  is a predetermined positive non-zero constant, and  $\Delta(m,n)$  denotes a discrete horizontal Laplacian signal that can be approximated as:

$$\begin{aligned}\Delta(m, n) &= (f(m, n+1) - f(m, n)) - (f(m, n) - f(m, n-1)) \\ &= f(m, n+1) - 2 \cdot f(m, n) + f(m, n-1).\end{aligned}$$

It is well known that by looking for the zero-crossing points of the Laplacian, the  
 5 Laplacian can be used for edge detection. For example, reference can be made to the  
 previously cited documents, “Fundamentals of Digital Image Processing”, and “Two  
 Dimensional Signal Processing and Image Processing”. On the contrary, when the  
 Laplacian has a large amplitude, or equivalently, as the value of  $y(m, n)$  approaches 1,  
 this indicates that there is a significant change in the first order difference signals around  
 10 the sample  $f(m, n)$ . This implies that it is likely that the sample  $f(m, n)$  is located at the  
 boundary of an edge. However, this is not necessarily the case because  $y(m, n)$  will also  
 have a large value in the case when the sample  $f(m, n)$  is located in the middle of a spike  
 signal, such as, that as illustrated in Fig. 6.

15 Now, by combining together the conditions explained in (9) and (10), we have a  
 sufficient condition to determine whether the current input sample  $f(m, n)$  is located at  
 the boundary of an edge for which the prior art enhancement might introduce Shoot  
 problems. That is, it can be easily asserted that the input sample  $f(m, n)$  is located at the  
 boundary of an edge if  $x(m, n)$  is approaching 0 and  $y(m, n)$  is approaching 1 at the  
 20 same time. The condition that  $x(m, n)$  approaches 0 implies that at least one of the  
 backward or the forward first order sample difference ( $f_L(m, n)$  or  $f_R(m, n)$ ) is small,  
 which means that at least one side is a constant region. Therefore, the condition that

$x(m,n)$  approaches 0 clearly excludes the case shown in Fig. 6, namely that the sample  $f(m,n)$  is in the middle of a spike signal. At the same time, the condition that  $y(m,n)$  approaches 1 implies that the sample  $f(m,n)$  is either located at the boundary of an edge or in the middle of a spike signal. Therefore, the condition that  $y(m,n)$  approaches 1  
 5 clearly excludes the case of a constant region. However, because  $x(m,n)$  is approaching 0, we have also excluded the case of a spike signal, and therefore, using the two criteria, we have a sufficient condition for concluding that the sample  $f(m,n)$  is located at the boundary of an edge.

10 Figs. 7A-7D show four possible cases that can be used to better understand the combined condition for detecting the boundary of an edge. Fig. 7A shows image samples representing a constant region where both  $x(m,n)$  and  $y(m,n)$  are small (close to 0). Fig. 7B shows samples of an edge point where  $x(m,n)$  is large (close to 1) and  $y(m,n)$  is small (close to 0). Fig. 7C shows samples of the boundary of an edge where  $x(m,n)$  is  
 15 small (close to 0) and  $y(m,n)$  is large (close to 1). Fig. 7D shows a spike signal where both  $x(m,n)$  and  $y(m,n)$  are large (close to 1).

Based on the combined conditions, it is now necessary construct the Shoot suppressing gain function  $\beta(m,n)$  such that the following boundary conditions are  
 20 satisfied:

$$\beta \rightarrow 1 \text{ as } x \rightarrow 0 \text{ and } y \rightarrow 0;$$

$$\beta \rightarrow 0 \text{ as } x \rightarrow 0 \text{ and } y \rightarrow 1;$$

$\beta \rightarrow 1$  as  $x \rightarrow 1$  and  $y \rightarrow 0$ ; and

$\beta \rightarrow 1$  as  $x \rightarrow 1$  and  $y \rightarrow 1$  (11).

As a first exemplary embodiment of such a function, the Shoot suppressing gain

5 function  $\beta$  can be implemented as:

$$\beta(m, n) = \beta(x(m, n), y(m, n)) = 1 - (1 - x(m, n))^p \cdot (y(m, n))^q \quad (12),$$

where  $p$  and  $q$  are pre-determined constants. Fig. 8 shows a plot of  $\beta(x, y)$  where

$p = 1.75$  and  $q = 0.75$ . Note here that the value of  $\beta(x, y)$  converges to zero only as

$x(m, n)$  and  $y(m, n)$  converge to 0 and 1, respectively, which is the condition that the

10 input sample  $f(m, n)$  is located at the boundary of an edge.

Some variations of the Shoot suppressing gain function  $\beta$  given in (12) can be generated that also have the same convergence characteristic as that specified in (11). For

instance, a second embodiment of the Shoot suppressing gain function  $\beta$  has the

15 convergence characteristic specified in (11) and is expressed by:

$$\beta(m, n) = 1 - (1 - x(m, n)^p) \cdot (y(m, n))^q. \quad (13).$$

It should now be apparent that a shoot suppressing gain function  $\beta$  can also be derived to prevent or suppress the occurrence of Shoots in the vertical direction. The

20 boundary conditions defined in (11) are still applicable and therefore, equations (12) and

(13) can also be used in this case. The only differences are that equations (6)-(8) will be

modified to operate in the vertical direction before being substituted into equation (9) and

a discrete vertical Laplacian signal will be approximated before being substituted into equation (10). The vertically acting equivalents of (6)-(8) are as follows:

$$f_L(m, n) = |f(m, n) - f(m - 1, n)|;$$

5

$$f_U(m, n) = |f(m, n) - f(m + 1, n)|; \text{ and}$$

$$d(m, n) = \min(f_L(m, n), f_U(m, n)).$$

10

The approximation of the discrete vertical Laplacian signal is as follows:  $\Delta(m, n) = f(m + 1, n) - 2 \cdot f(m, n) + f(m - 1, n)$ .

15

In order to enhance a digital image while suppressing shoots in both the vertical and horizontal directions, both a shoot suppressing gain function  $\beta_h$  for suppressing shoots in the horizontal direction and a shoot suppressing gain function  $\beta_v$  for suppressing shoots in the vertical direction can be substituted equation (5) so that  $\beta = \beta_v^* \beta_h$ .